PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G08B 17/107	A1	(11) International Publication Number: WO 99/19852 (43) International Publication Date: 22 April 1999 (22.04.99)

(21) International Application Number: PCT/GB98/03079

(22) International Filing Date: 13 October 1998 (13.10.98)

(30) Priority Data:
9721861.4 15 October 1997 (15.10.97) GB

(71) Applicant *(for all designated States except US)*: KIDDE FIRE PROTECTION LIMITED [GB/GB]; Pentagon House, Sir Frank Whittle Road, Derby (GB).

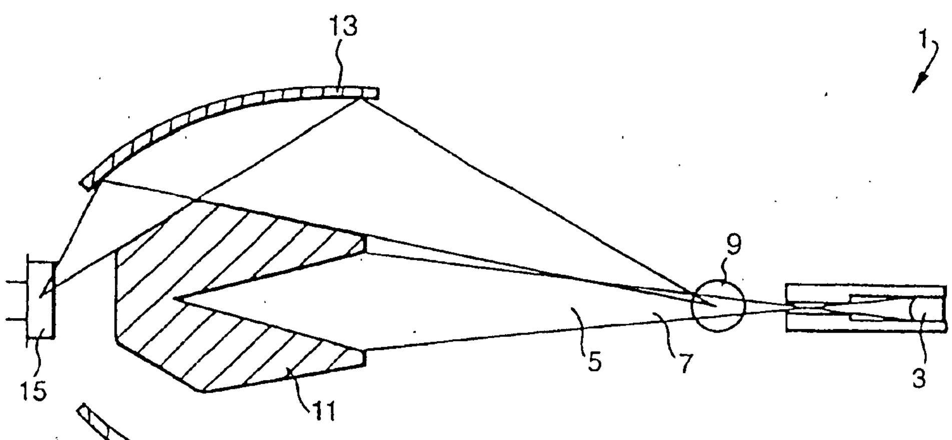
(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: POWELL, Brian [GB/GB]; 22 Loosen Drive, Maidenhead, Berkshire SL6 3UR (GB).

(74) Agent: MATHISEN, MACARA & CO.; The Coach House, 6–8 Swakeleys Road, Ickenham, Uxbridge, Middlesex UB10 8BZ (GB).

(81) Designated States: AU, JP, US, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: HIGH SENSITIVITY PARTICLE DETECTION



(57) Abstract

A smoke detector is shown in which smoke particles are detected by the collection and detection of blue light emitted from a radiation source (3) and scattered by the particles. The emitted radiation (7) is passed into a volume (9) and is scattered by any smoke particles present. Scattered radiation is collected by an ellipsoidal mirror (13) and focussed on a silicon photodiode (15). The light collected by the mirror (13) has been scattered through angles substantially less than 45° and preferably between about 10° and 35°.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania
AM	Armenia
AT	Austria
AU	Australia
AZ	Azerbaijan
BA	Bosnia and Herzegovina
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CU	Cuba
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GH	Ghana
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakstan
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
TR	Turkey
TT	Trinidad and Tobago
UA	Ukraine
UG	Uganda
US	United States of America
UZ	Uzbekistan
VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

HIGH SENSITIVITY PARTICLE DETECTION

The invention relates generally to high sensitivity particle detection. Embodiments of the invention to be described in more detail, by way of example only, are for detecting the presence of smoke particles.

According to the invention there is provided a particle detector for detecting particles of sizes of less than 1 micron, comprising radiation emitting means for emitting radiation along a predetermined path through a scattering volume, and radiation detection means for receiving and detecting radiation scattered at a predetermined forward scattering angle from the scattering volume by the presence of particles, the angle being less than 45° to the predetermined path of radiation, and the wavelength of the radiation being between about 400nm and about 500 nm.

According to the invention, there is also provided a particle detecting method for detecting particles of sizes of less than 1 micron, comprising the steps of emitting radiation along a predetermined path through a scattering volume, and receiving and detecting radiation scattered at a predetermined forward scattering angle from the scattering volume by the presence of

particles, the angle being less than 45° to the predetermined path of radiation, and the wavelength of the radiation being between about 400nm and about 500 nm.

High sensitivity particle detection apparatus and methods according to the invention will now be described, by way of example only, with reference to the accompanying diagrammatic drawings in which:-

Figure 1 is a schematic diagram of one form of the apparatus;

Figures 2,3 and 4 are graphs for explaining the operation and advantages of the apparatus of Figure 1;

Figure 5 corresponds to Figure 1 but shows a modified form of the apparatus; and

Figures 6 and 7 are graphs for explaining the operation and advantages of the apparatus of Figure 5.

The apparatus and methods to be described are for detecting smoke in air using light scattering techniques, although it will be appreciated that other particles can be detected using the same apparatus and methods. The apparatus and methods aim to detect the presence of smoke particles at smoke densities

at least as low as 0.2% per metre. The primary use of such apparatus is for detecting incipient fires.

The apparatus 1 (Figure 1) comprises a radiation source 3 emitting radiation along a path 5. Radiation 7 passes through a volume 9 towards a beam dump 11. An ellipsoidal mirror 13 is positioned for collecting radiation scattered by the presence of smoke particles in the volume 9 (within a predetermined range of forward scattering angles to be discussed below) and focussing such radiation on a silicon photodiode 15.

It will be appreciated that the collection means for the scattered radiation need not be an ellipsoidal mirror 13 but may be any suitable collection means. Additionally, it will also be appreciated that any suitable detector means may be used and the detector need not be silicon photodiode 15.

In use, radiation 7 from the radiation source 3 is emitted along the path 5 through the scattering volume 9. The presence of any smoke particles in the scattering volume 9 will cause the radiation 7 to be scattered through a predetermined range of angles. The ellipsoidal mirror 13 is positioned such that any light scattered at forward scattering angles of less than 45°, and more particularly at scattering

angles between about 10° and 35° will be collected by the ellipsoidal mirror 13. The ellipsoidal mirror 13 focuses the light scattered at these angles from the scattering volume in all planes perpendicular to the incident radiation direction on to the silicon photodiode 15. This arrangement maximises the radiation incident on the photodiode 15. The signal produced by the silicon photodiode 15 may be used to trigger a suitable alarm system and/or a fire extinguishing system.

Any radiation which is not scattered will be incident on and be trapped substantially by the beam dump 11 and no corresponding signal will be produced by the silicon photodiode 15.

The radiation source 3 emits radiation 7 at relatively short wavelengths between about 400nm and 500nm, that is, blue visible light; preferably, the radiation source 3 is an LED producing radiation at 470 nm wavelength. It is found that the use of this relatively short wavelength, combined with the use of relatively small forward scattering angles, produces increased sensitivity of particle detection, at least for smoke particles This is explained in more detail with reference to Figures 2 to 4.

Curve A in Figure 2 shows the output of the detector 15 for

different degrees of smoke obscuration expressed as a percentage of light obscured per metre. Curves B, C, D and E show the corresponding detector outputs at the same scattering angle but for different (longer) radiation wavelengths. Curve B shows the detector output where the radiation is in the green part of the spectrum. Curve C shows the detector output where the radiation is in the red part of the spectrum. Curve D shows the detector output when the radiation is in the infra-red part of the spectrum and of the order of 880 nm. Finally, curve E shows the detector output when the radiation is in the infra-red part of the spectrum and of the order of 950 nm. In each case, the range of forward scattering angles is the same (between about 10° and 35°). The smoke for the tests illustrated was produced by smouldering cotton.

Figure 2 clearly shows the increased detector output, and thus the increased sensitivity of detection, which is obtained by using a radiation source producing blue visible light of the order of 470 nm. Figure 2 shows how detectable signals can be produced from the photodiode 15 at smoke densities as low as 0.2% per metre. Radiation at the other wavelengths (curves B, C, D and E) produces significantly lower outputs.

Shorter wavelength light also has the advantage that it has a lower reflectivity from typical matt black surfaces. By

suitable design of the detecting apparatus, therefore, the output from the photodiode 15 due to background scattered light signals (primarily signals reflected from internal surfaces of the apparatus and not due to smoke) can be made very small - and significantly less than when light of longer wavelengths is used.

Figure 3 plots the calculated scattering gain for a particle size distribution typical of smoke against the forward scattering angle using light at different wavelengths. Scattering gain is the amount of light scattered into a unit solid angle as a fraction of the light falling on an individual particle. Curve A corresponds to blue visible light, curve B to green visible light, curve C to red visible light, curve D to infra-red radiation of the order of 880 nm, and curve E to infra-red radiation of 950 nm. Figure 3 shows how the use of blue visible light (curve A) produce significantly more scattering gain than radiation at the other wavelengths (curves B to E) at scattering angles up to about 155°, although the increase in scattering gain is much more pronounced at scattering angles less than 45°.

Curves A in Figures 2 and 3 therefore show how the combination of the use of blue visible light (radiation between 400 and 500nm) and the use of low scattering angles (between about 10°

and 35°) produces a significant increase in sensitivity.

Smoke detectors may be susceptible to false alarms in the presence of larger aerosol particles such as condensed water mist or dust. Figure 4 corresponds to Figure 3 except that the particles used are particles having a size distribution typical of condensed water mist, and calculations were carried out for only two wavelengths: blue visible light at 450 nm (curve A), and infra-red radiation at 950 nm (curve E). Curves A and E in Figure 4 show that the scattering gain is substantially the same at both the wavelengths tested, at least for scattering angles between about 15° and 30°. A comparison of Figures 3 and 4 therefore shows that the ratio (signal to noise ratio) between the output of the photodiode in response to smoke particles and the corresponding output for "nuisance" aerosols, such as water mist particles, will be higher when blue light is used than when radiation at the other wavelengths is used.

Figure 5 shows a modified arrangement of Figure 1 which uses the principle illustrated by comparing Figures 3 and 4. In Figure 5 items corresponding to items in Figure 1 are similarly referenced. In Figure 5, the source 3 of Figure 1 is supplemented by a source 3A. Source 3 produces blue light, as before, in the range 400 to 500 nm. Source 3A produces

infra-red radiation at about 880 nm and may (like source 3) be an LED. The radiation emitted by both sources is passed via a beam splitter 17 and thence through the volume 9.

As before, radiation forward-scattered (at the appropriate angles) by obscuration in the volume 9 is collected by the ellipsoidal mirror 13 and focussed an detector 15. As before, detector 15 is a silicon photodiode. Such a detector is sensitive to blue light and also infra-red radiation at about 880nm. A control system indicated generally at 19 and 20 enables the detector 15 to produce separate outputs on lines 21 and 23 corresponding respectively to the scattered blue light and the scattered infra-red radiation as received by the detector. The control system 19,20 may take any suitable form. For example, it may arrange to pulse the sources 3 and 3A alternately and to switch the detector output synchronously between the lines 21 and 23. Instead, the sources 3 and 3A can be energised separately at different frequencies and separate narrow band or lock-in amplifiers can be used for responding to the output from the detector and for respectively energising the lines 21 and 23. The outputs of the detector 15 on lines 21 and 23 are processed by a comparison unit 25.

Figures 6 and 7 illustrate the operation of the arrangement of

Figure 5.

In Figures 6 and 7, the horizontal axis represents time, the left hand vertical axis represents visible obscuration expressed as a percentage of light obscured per metre, and the right hand vertical axis represents the output of the detector 15 in Figure 5. The left and right hand axis are to a logarithmic scale.

Figure 6 shows results obtained when obscuration is caused by smoke (in this case, grey smoke produced by smouldering cotton), the smoke being released for 5s at 100s and then for 100s between 200 and 300s. In Figure 7, the obscuration is caused by a non-smoke source, in this case by a hairspray aerosol. A one second spray is released at 100s and a 10s spray at 200s.

In Figure 6, curve I plots the obscuration. Curve II plots the output of the detector 15 in response to the blue light emitted by the source 3. Curve III plots the output of detector 15 in response to the infra-red radiation emitted by source 3A. It will be seen that the detector output in response to the scattered infra-red radiation (Curve III) is much less than the detector output in response to the scattered blue light (curve II). Curve IV shows the ratio of

the detector output when the emitted radiation is blue light (curve II) to the output when the emitted radiation is infra-red (curve III). The ratio is significantly greater than one.

In Figure 7, the curves I,II,III and IV have the same identities as in Figure 6. It will be noted that the ratio shown by curve IV is significantly less than one.

The unit 23 is therefore arranged to measure the ratio of the output of detector 15 to the output of detector 15A. If this ratio is more than one, obscuration by smoke is signalled. If the ratio is less than one, smoke obscuration is not signalled.

The infra-red radiation used in the embodiment of Figure 5 does not need to be at 880nm.

CLAIMS

1. A particle detector for detecting particles of sizes of less than 1 micron, comprising radiation emitting means (3) for emitting radiation along a predetermined path through a scattering volume (9), and radiation detection means (15) for receiving and detecting radiation scattered at a predetermined forward scattering angle from the scattering volume by the presence of particles, characterised in that the angle is less than 45° to the predetermined path of radiation, and the wavelength of the radiation is between about 400nm and about 500 nm.

2. A detector according to claim 1, characterised in that the particles are smoke particles.

3. A detector according to claim 1 or 2, characterised in that the detecting means (3) is a photodiode.

4. A detector according to claim 1, characterised by second radiation emitting means (3A) for emitting infra-red radiation along the predetermined path through the scattering volume (9), second radiation detecting means (15A) for receiving and detecting the infra-red radiation scattered at the predetermined forward scattering angle from the scattering volume (9) by the presence of the particles, and output means

(23) for comparing the outputs of the two detecting means (15,15A) whereby to produce a warning output when the comparison indicates that the particles are of a predetermined type but not when the comparison indicates otherwise.

5. A detector according to claim 4, characterised in that the output means (23) measures the ratio between the outputs of the detecting means (15,15A).

6. A detector according to claim 4 or 5, characterised in that the particles of the predetermined type are smoke particles.

7. A detector according to any preceding claim, characterised in that the or each radiation emitting means (3,3A) is an LED.

8. A detector according to any preceding claim, characterised in that the predetermined scattering angle lies in a range between about 10° and 35°.

9. A detector according to any preceding claim, characterised by collecting and focussing means (13) for collecting the scattered radiation and focussing it on the or each detection means (15,15A).

10. A detector according to claim 9, characterised in that the collecting and focussing means is an ellipsoidal mirror (13).

11. A detector according to any preceding claim, characterised by beam dump means (11) positioned in the predetermined path and further from the radiation emitting means (3,3A) than the scattering volume (9).

12. A particle detecting method for detecting particles of sizes of less than 1 micron, comprising the steps of emitting radiation along a predetermined path through a scattering volume (9), and receiving and detecting radiation scattered at a predetermined forward scattering angle from the scattering volume (9) by the presence of particles, characterised in that the angle is less than 45° to the predetermined path of radiation, and the wavelength of the radiation is between about 400nm and about 500 nm.

13. A method according to claim 12, characterised in that the particles are smoke particles.

14. A method according to claim 12, characterised by the step of emitting infra-red radiation along the predetermined path through the scattering volume (9), receiving and detecting the

infra-red radiation scattered at the predetermined forward scattering angle from the scattering volume (9) by the presence of the particles, and comparing outputs respectively corresponding to the detected radiation between about 400nm and about 500nm and the detected infra-red radiation whereby to produce a warning output when the comparison indicates that the particles are of a predetermined type but not when the comparison indicates otherwise.

15. A detector according to claim 14, characterised in that the comparison step comprises the step of measuring the ratio between the compared outputs.

16. A detector according to claim 14 or 15, characterised in that the particles of the predetermined type are smoke particles.

17. A method according to any one of claims 13 to 16, characterised in that the predetermined scattering angle lies in a range between about 10° and 35°.

18. A method according to any one of claims 12 to 17, characterised by the step of collecting and focussing the scattered radiation.

Fig.1.

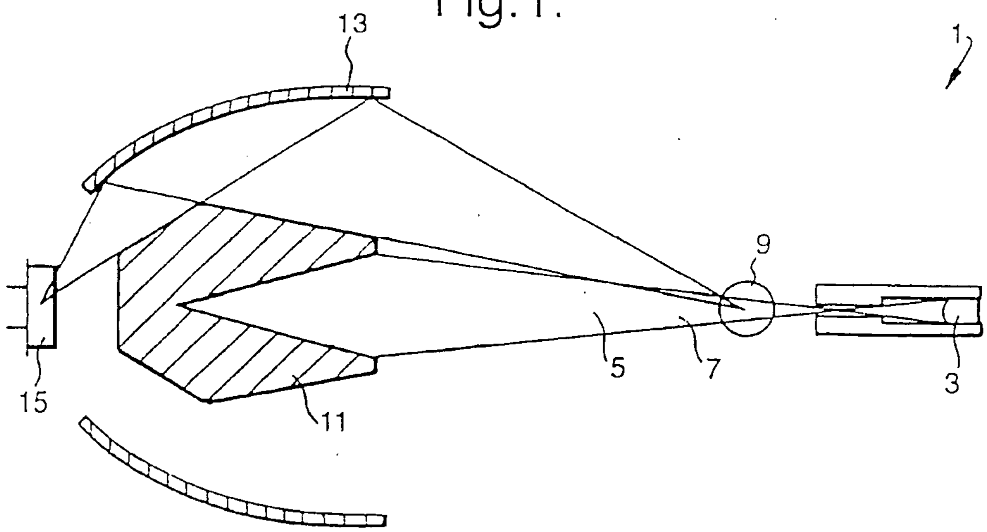


Fig.2.

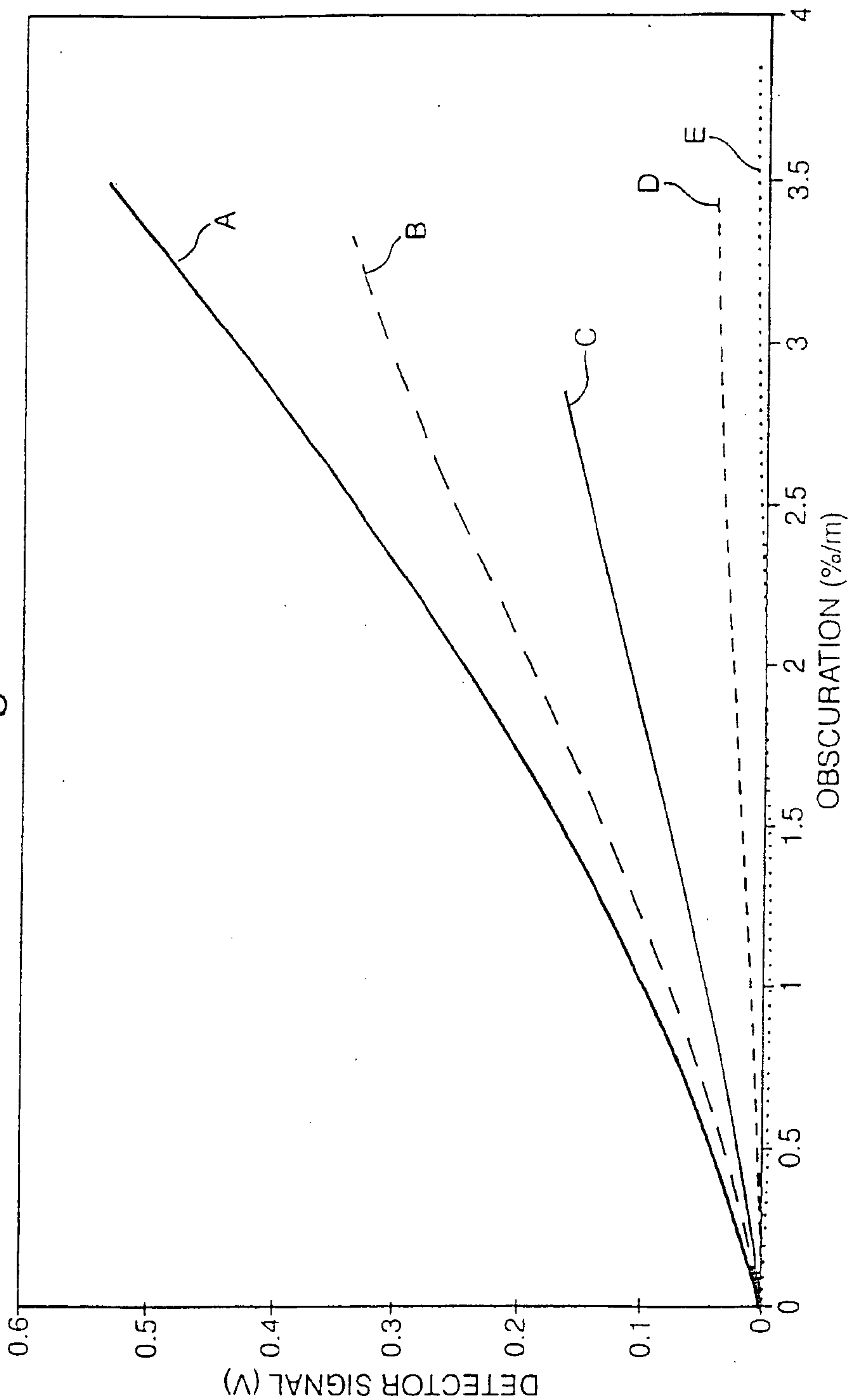

DETECTOR SIGNAL (V)
0.6
0.5
0.4
0.3
0.2
0.1
0
OBSCURATION (%/m)
0
0.5
1
1.5
2
2.5
3
3.5
4
A
B
C
D
E

Fig.3.

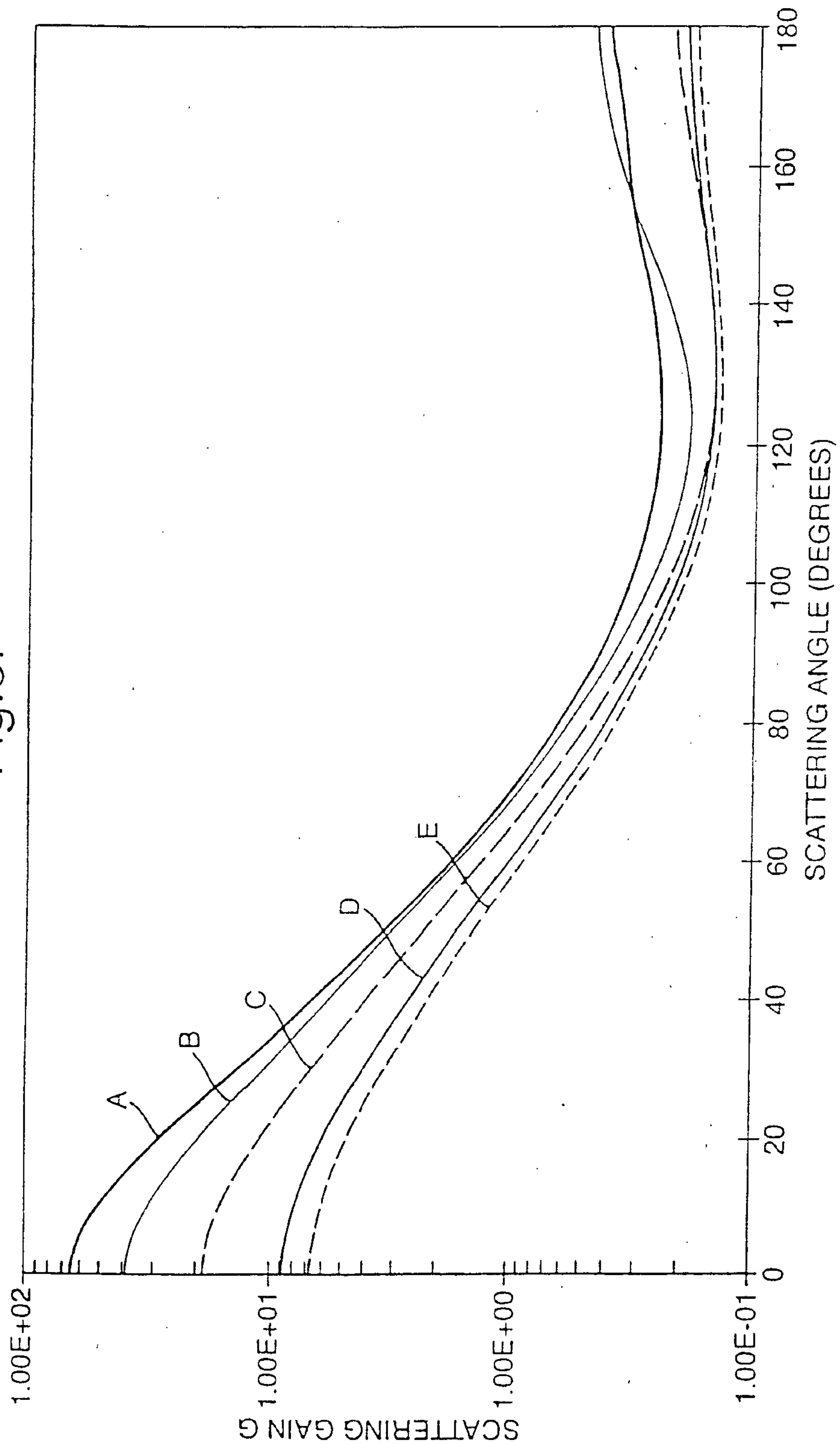
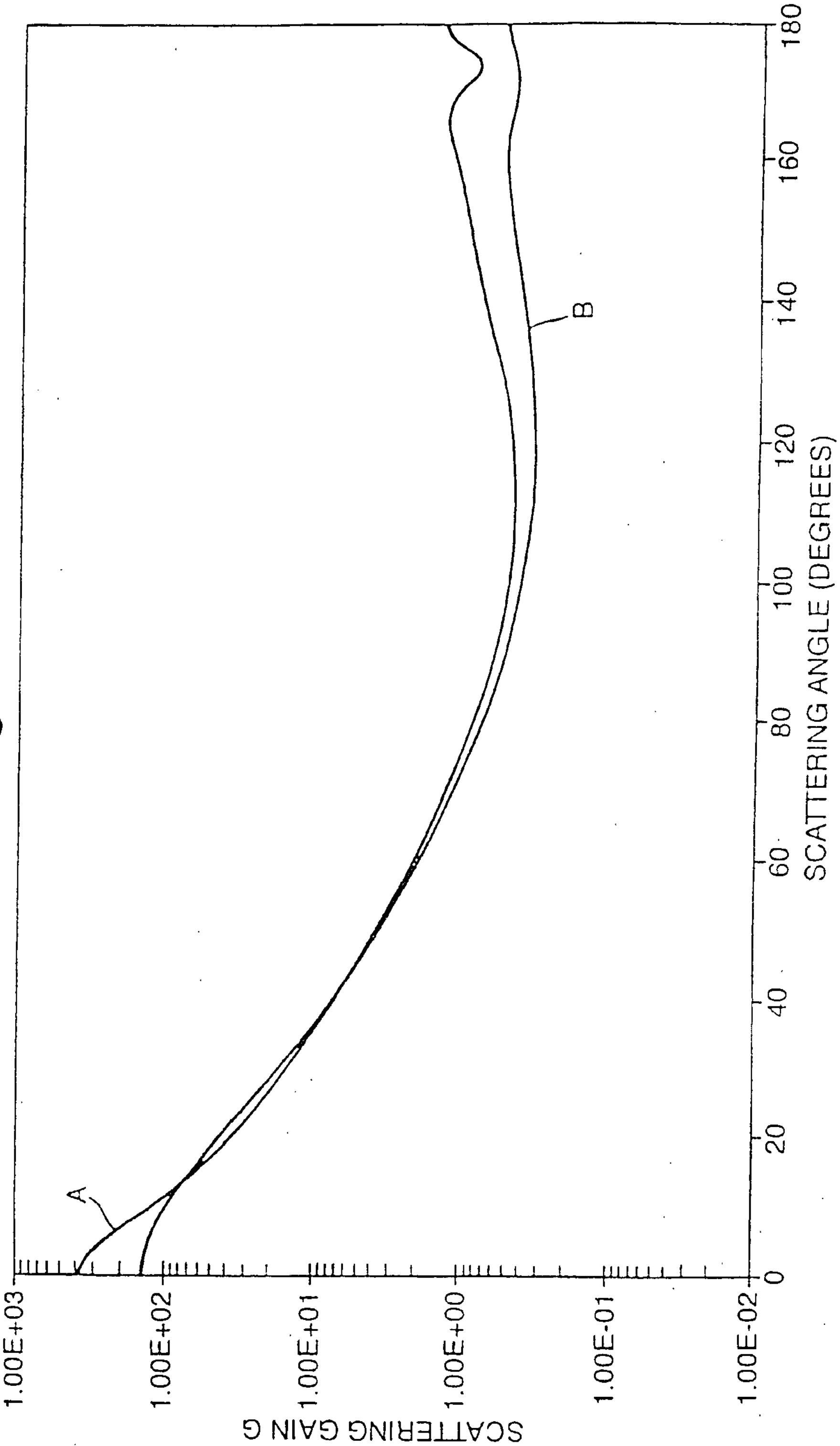

A
B
C
D
E
1.00E+02
1.00E+01
1.00E+00
1.00E-01
SCATTERING GAIN G
0
20
40
60
80
100
120
140
160
180
SCATTERING ANGLE (DEGREES)

Fig.4.


SCATTERING GAIN G
1.00E+03
1.00E+02
1.00E+01
1.00E+00
1.00E-01
1.00E-02
SCATTERING ANGLE (DEGREES)
0
20
40
60
80
100
120
140
160
180
A
B

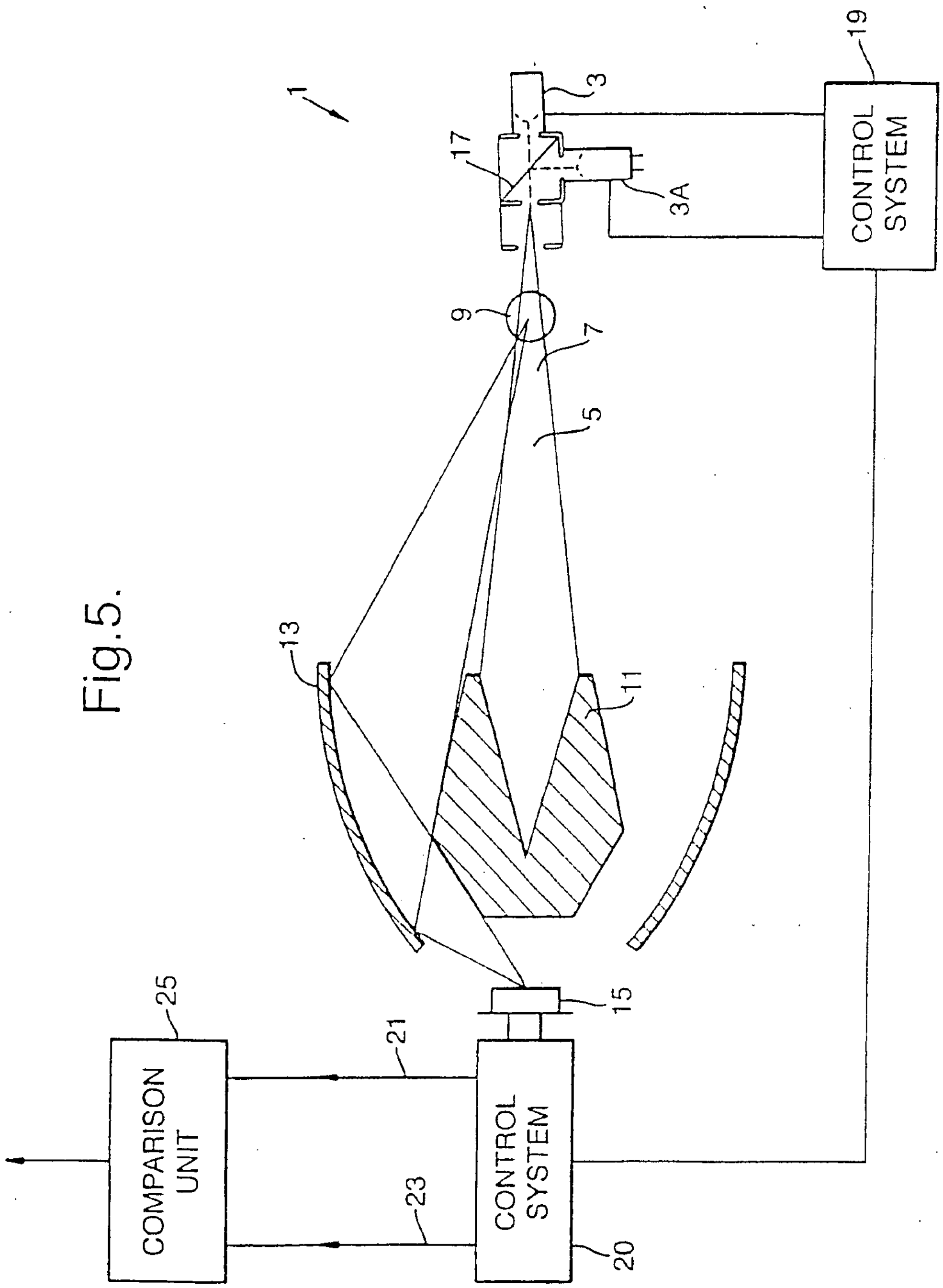

1
3
3A
17
19
CONTROL SYSTEM
9
7
5
13
11
15
21
23
25
20
CONTROL SYSTEM
COMPARISON UNIT

Fig.5.

Fig.6.

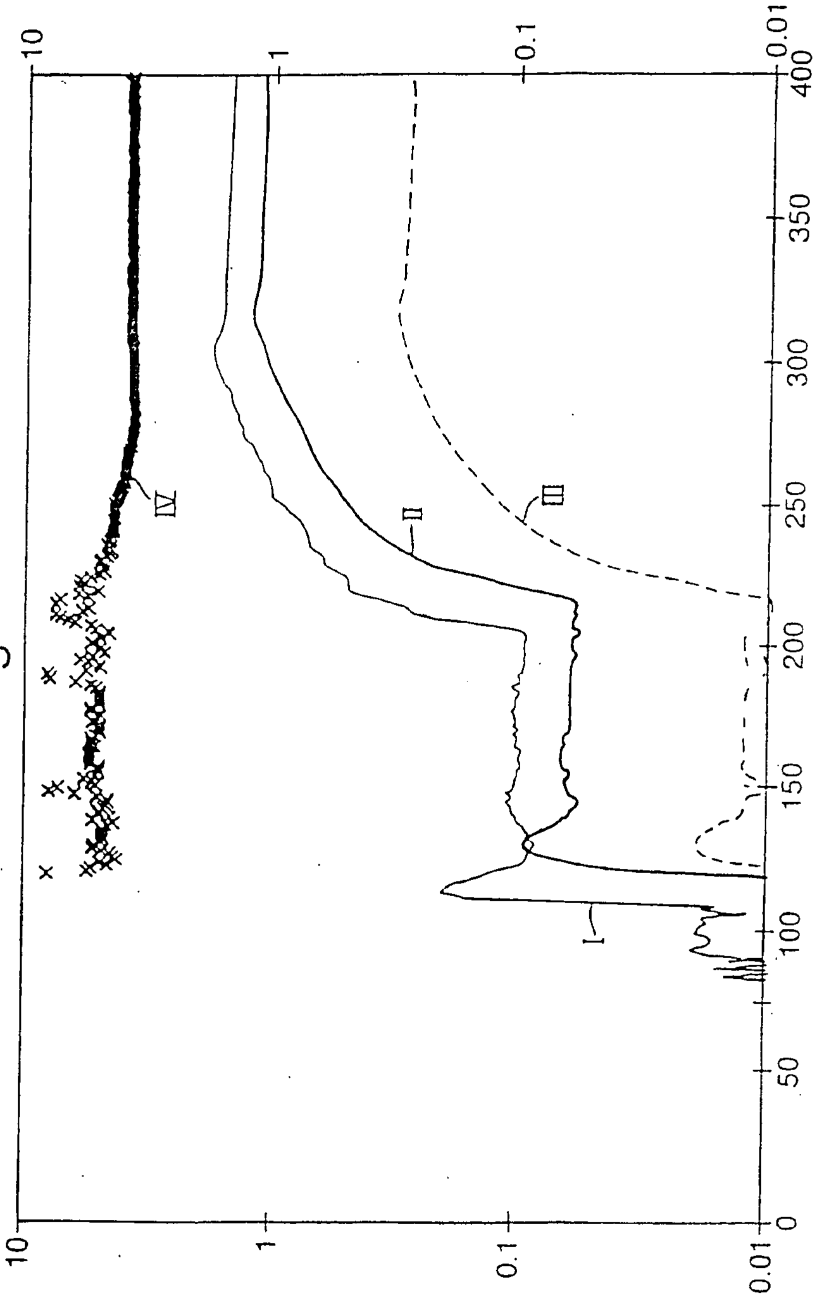
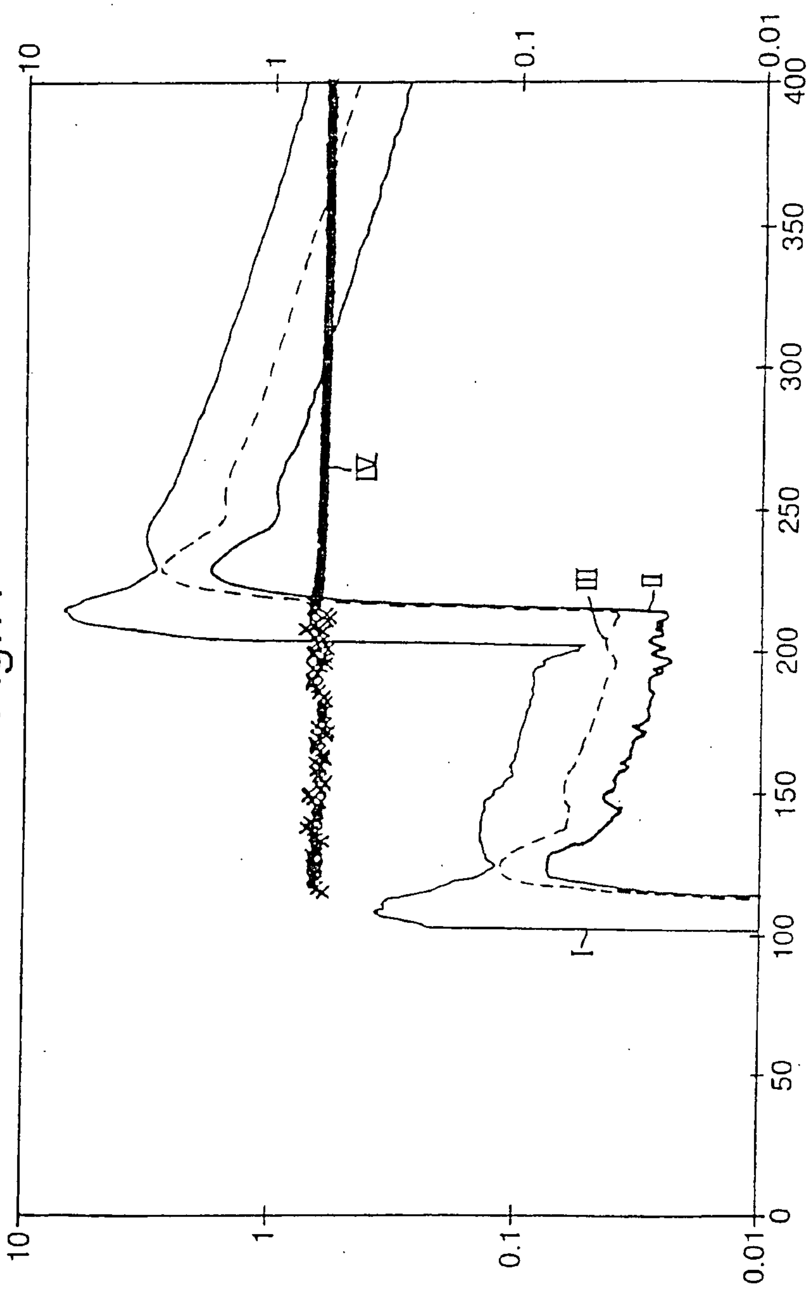


Fig.7.



INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 98/03079

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G08B17/107

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G08B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GOODMAN D S: "METHOD FOR LOCALIZING LIGHT-SCATTERED PARTICLES" IBM TECHNICAL DISCLOSURE BULLETIN, vol. 27, no. 5, October 1984, page 3164 XP002066860 see the whole document ---	1-18
A	WO 89 09392 A (COLE MARTIN TERENCE) 5 October 1989 see figures 1,2 -----	1-18

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 January 1999	27/01/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Sgura, S

1

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int ional Application No
PCT/GB 98/03079

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 8909392 A	05-10-1989	AU 3413089 A	16-10-1989
		EP 0407429 A	16-01-1991
		US 5392114 A	21-02-1995